LIST Field Testing

A Wind Turbine Inflow and Loads Correlations Study

at the Colorado Green Wind Farm, Lamar, Colorado

November 17, 2004

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Presentation Topics

- What are the issues?
- Research approach
- Past LIST programs
- Current LIST program
- LIST program future plans

Issues

- What atmospheric phenomena generate turbulence characteristics that contribute to fatigue failure of turbine components?
- Do current turbulence models create wind conditions that accurately predict turbine response?
- Is there a 'floor' to the fatigue load spectrum, or can it be extrapolated?

Research Approach

- Embark on measurement campaigns to obtain detailed inflow and corresponding wind turbine response
  - Identify interaction between wind turbine and turbulence structures associated with atmospheric phenomena near specific geographic features (e.g. Great Plains)
- Incorporate identified wind characteristics in empirical simulation codes – presented later by Neil Kelley

LIST Program

- Long-term – one or more wind seasons
- Inflow – turbulence and thermodynamic characteristics of wind in various geographic locations
- Structural – extreme loads and component fatigue damage resulting from inflow
- Test – experimental measurement campaign
  - Bushland, TX (Campaign I-330 hrs; II-1000+hrs)
  - NWTC, CO (2000-2001 wind season)
  - Lamar, CO (2004 - ??)

LIST – Bushland, TX (Fatigue)

COLLABORATIONS

USDA

University of Texas at Austin

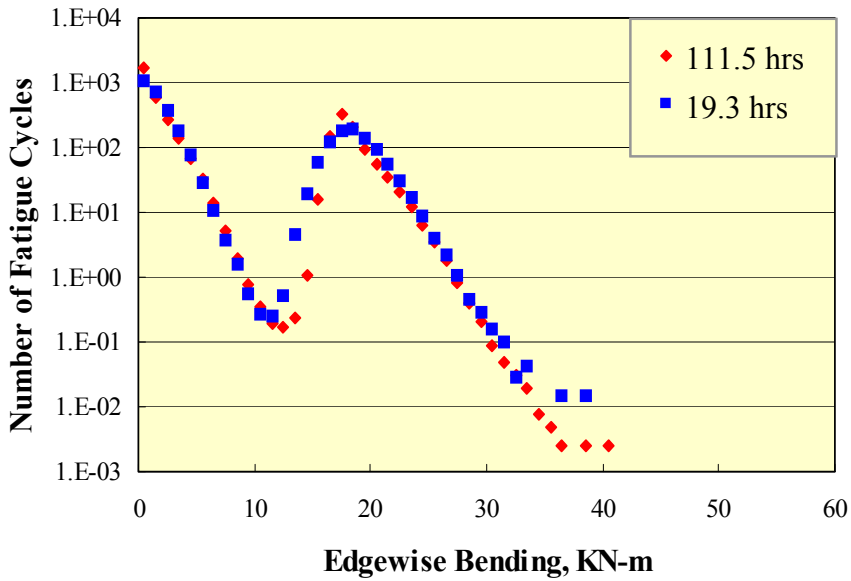
University of Waterloo

UC Davis

NASA

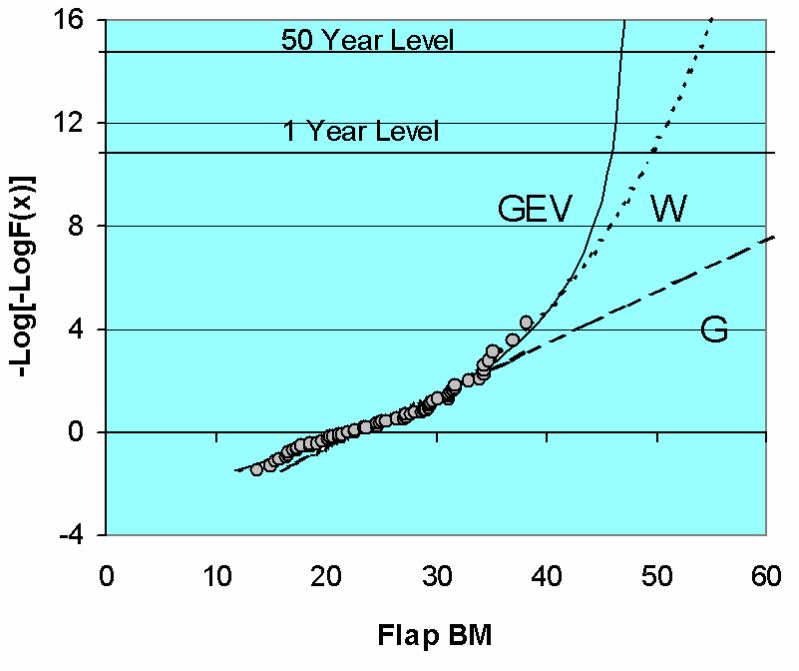
PUBLICATIONS

- Description of Measurement Campaigns: 6
- Use of the Database: 8+
- Graduate Theses: 3



Refine Fatigue Loads

LIST – Bushland, TX (Extreme)



Extreme Design Load Analysis

- Reduce Conservative Design Allowables
- Validate Design Load Methodology
  - Extreme Loads
  - Fatigue Loads
- Refine Loads Used in Verification Testing
- Define Site-Specific Design Loads
  - On-Shore
  - Off-Shore

LIST – NWTC, CO

- Demonstrated correlation between high equivalent fatigue loads and atmospheric stability, Reynolds stress field, and buoyancy length scales associated with the nocturnal boundary layer up to heights of 58 m above ground.

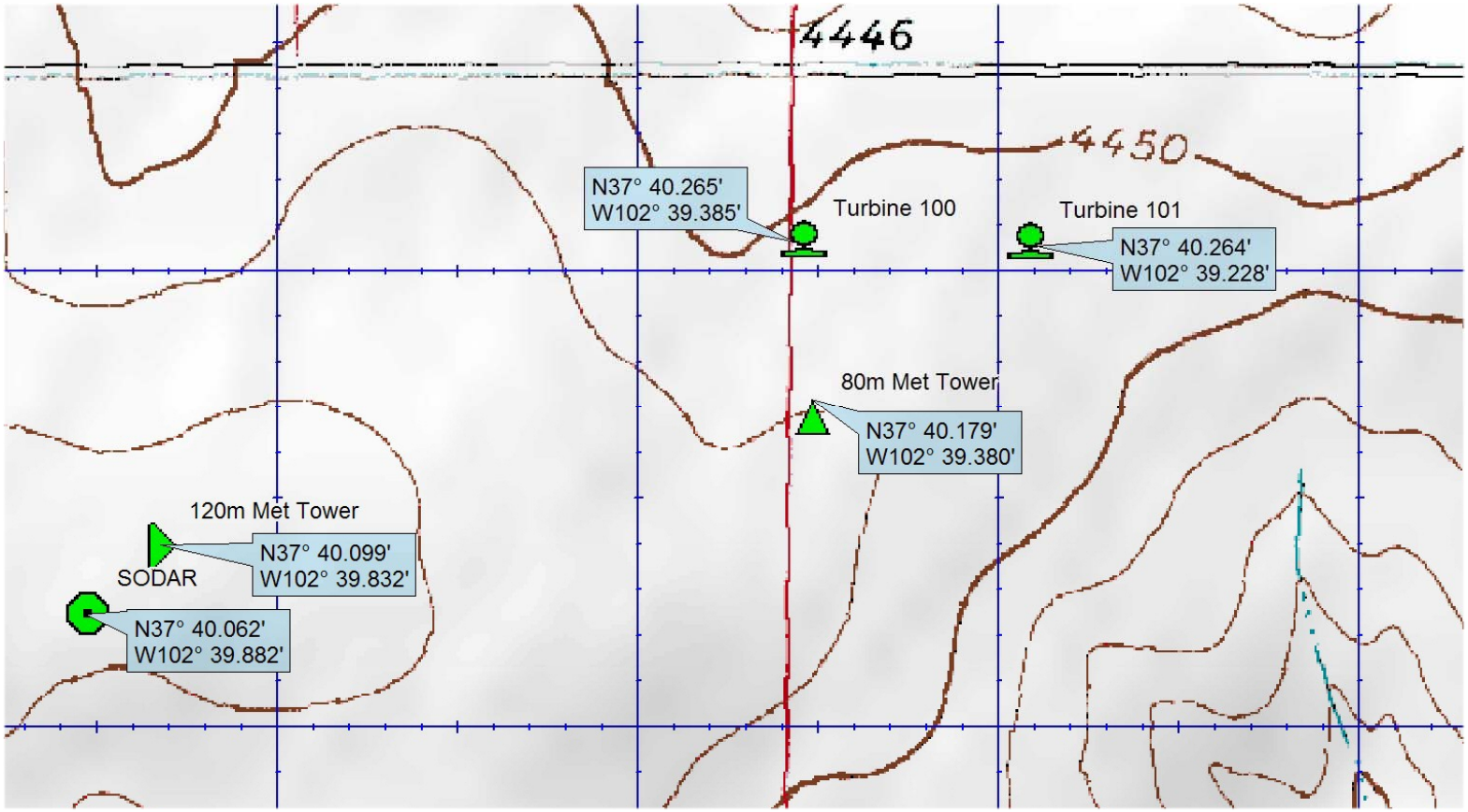
  Kelley et al., 2004, Lamar Low-Level Jet Project Interim Report, NREL-TP-500-34593; 3 conference papers

NREL, SNL, and GE Wind LLJ-LIST Lamar Project

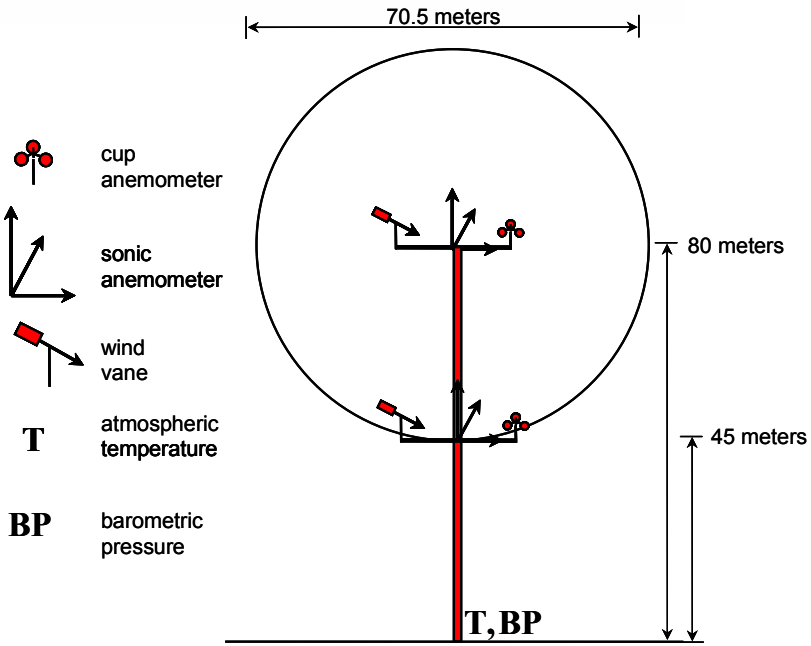
- Partnership formed among NREL, SNL, and GE Energy, to measure loads and corresponding inflow on a utility scale wind turbine at heights up to 113 m at Great Plains wind site (CRADA SC03/01683.02)
- Additional instrumentation on 120 m tower provides detailed turbulence and thermodynamic measurements near turbine.
- Acoustic wind profiler (SODAR) measures vertical wind profile up to 500 m above ground level.

- Objective
  - Quantify interaction between coherent turbulence associated with atmospheric phenomena such as low-level jets and wind turbine response
  - Validate design and analysis methods for turbine loads and fatigue

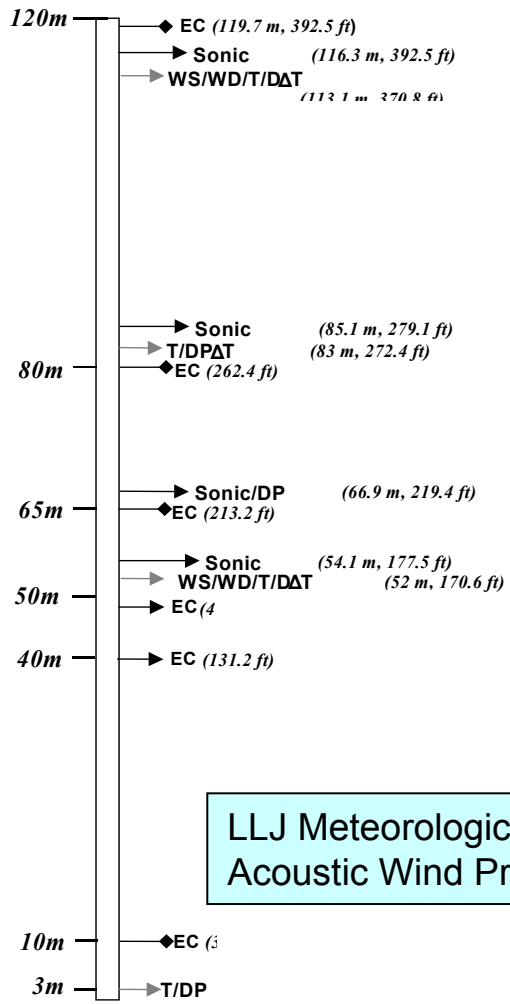
Colorado Green Test Site Layout



Inflow Instrumentation



Inflow Meteorological Tower

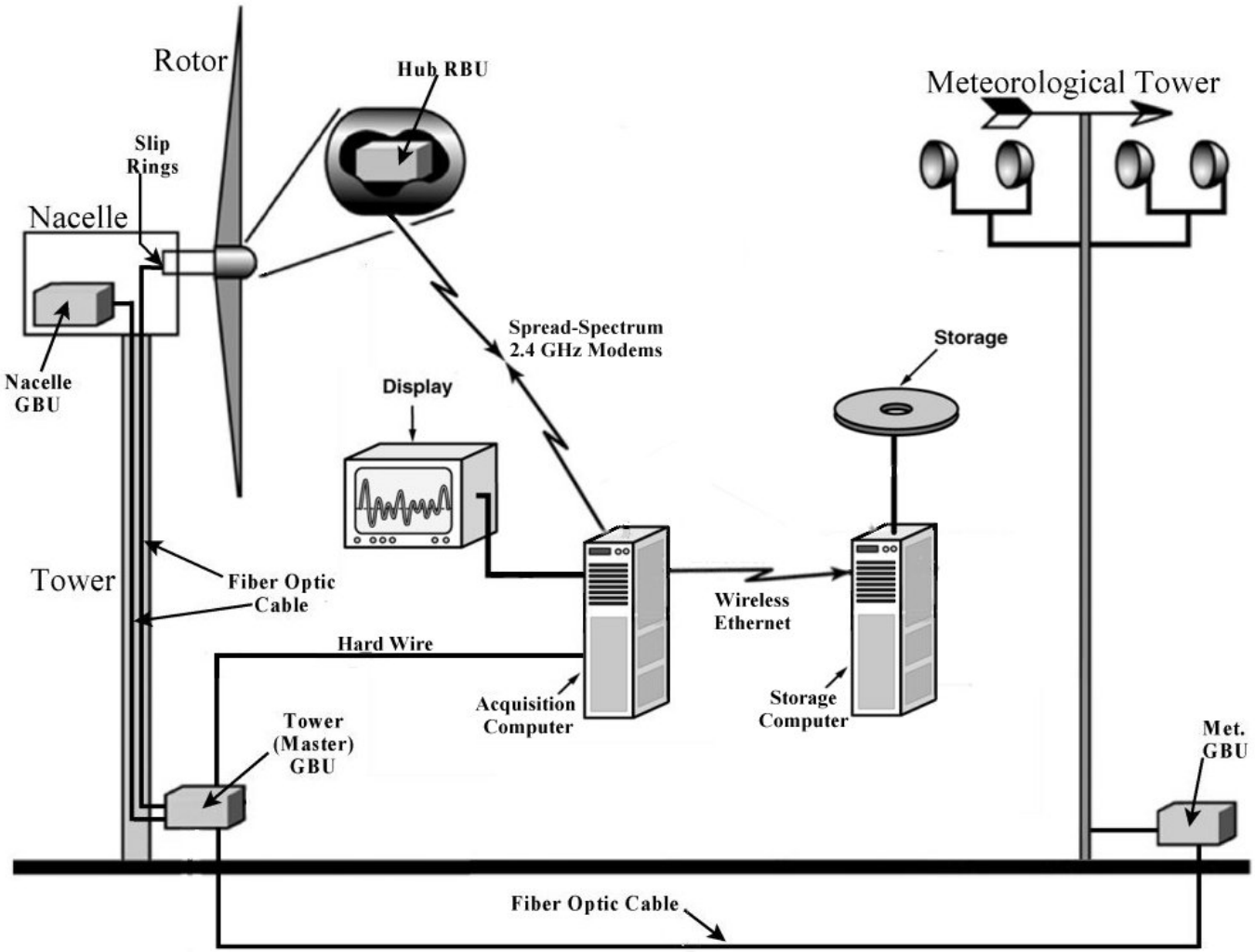


LLJ Meteorological Tower and Acoustic Wind Profiler

Wind Turbine Instrumentation (SNL)

- **GE 1.5MW Wind Turbine, Colorado Green Site**
  - 72 m rotor diameter on an 80 m tower
- **SNL ATLAS II Data Acquisition Systems for turbine and local met tower**
  - 64 channels – 40 Hz – ~ 2.5 GB Daily (uncompressed)
  - Loads measurements include blade root bending, main-shaft bending and torque, tower bending and torsion, gearbox and main bearing acceleration and rotation rate.

ATLAS II Configurations

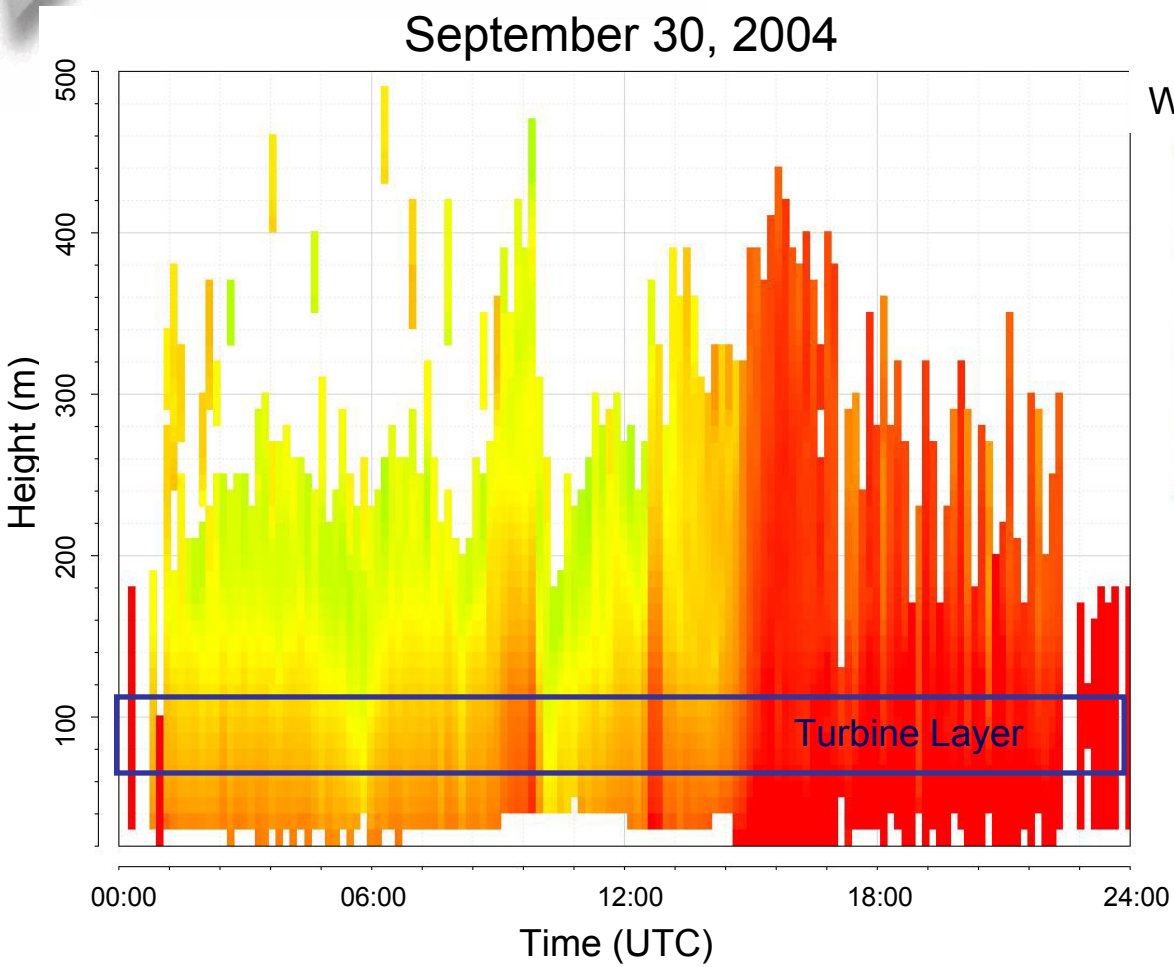


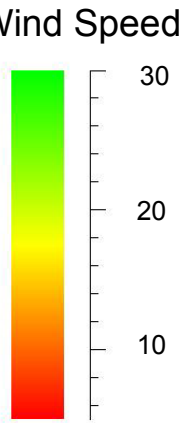
LLJ Tower Instrumentation (NREL)

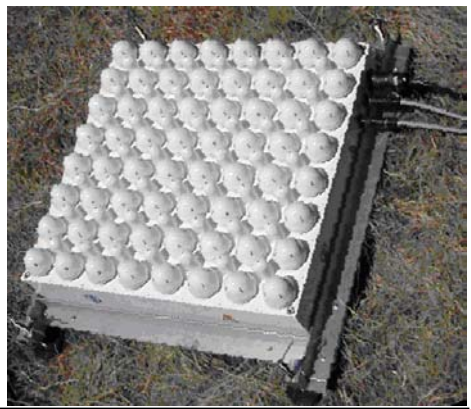
- 42 channels – 20 Hz – ~ 572 MB Daily (raw and processed)
- Four sonic anemometers from 54 m to 113 m; 2 cup anemometers; 2 wind direction vanes; 3 absolute and 2 delta temperature, 4 dew point temperature, and pressure
- Obtain detailed turbulence and thermodynamic characteristics of atmospheric layers encompassing turbine rotor

NREL Low-level Jet meteorological tower

Example of possible low-level jet

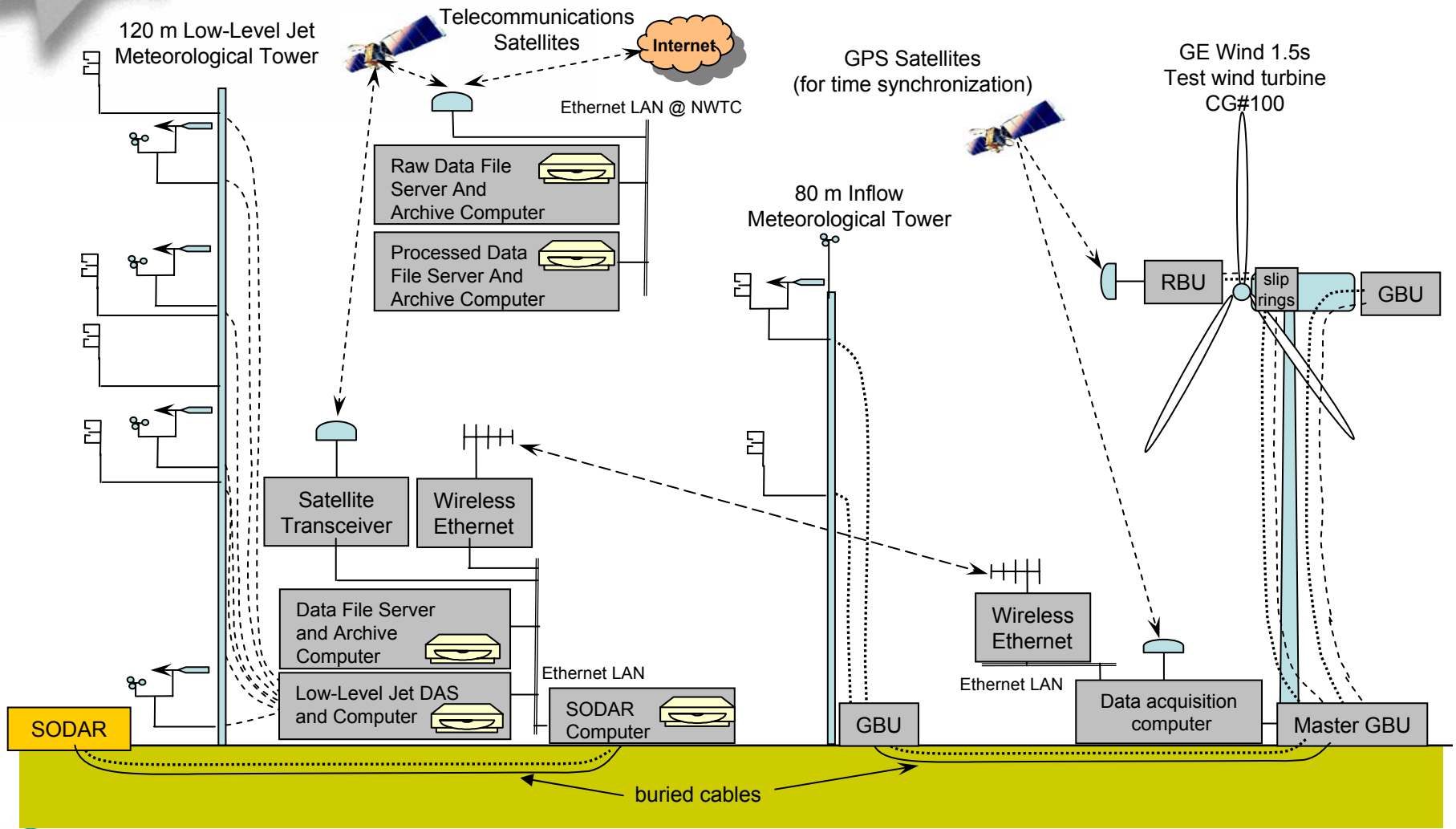






Acoustic wind profiler (SODAR)

Colorado Green Test Site Diagram



LLJ-LIST Project Current Status

Commission Date: September 14, 2004

Project Duration: project assessment after 3-months with option to continue for 1 year

Turbine Data Set Size: 7499 10-minute records, 19.9 GB of raw data (as of November 9, 2004)

LLJ Tower Data Set Size: 7871 10-minute records, 7.3 GB of raw data (as of November 9, 2004)

SODAR Data Preliminary Result: 7/55 daily records strong indication of low-level jet formation

Data Availability: GE Energy personnel access processed data via secure web interface

Proposed Publications:

1) **A Wind Turbine Blade Load Study at a Great Plains Wind Site, Submitted to AWEA 2005.**

2) **A Secure Data Collection Method for Wind Turbines Using an Internet Option, Submitted to AWEA 2005.**

3) **GE Energy/NREL/SNL LLJ-LIST Experiment Test Plan, CRADA SC03/01683.02.**

LIST Plans 2005-2006

- **Continue data collection to obtain one year record**
  - Estimate 460 GB of raw and processed data
- **FAST and/or ADAMS loads and turbulence validation studies**
- **Produce final report assessing interaction between wind turbine and turbulent flow field at Great Plains site**

LIST Plans Beyond 2007

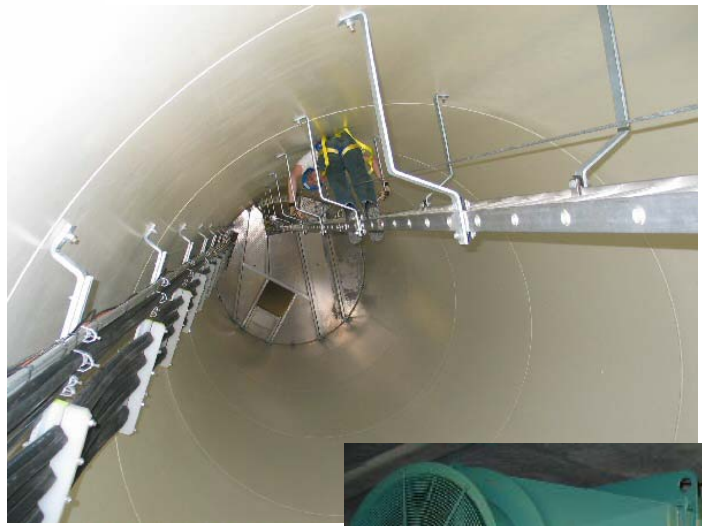
- **Duplicate measurement campaign for other geographically interesting sites (e.g., low-wind speed turbine site, offshore, …) to identify associated atmospheric turbulence generation mechanisms and quantify their effect on wind turbine operation**

Colorado Green LLJ and LIST Project Staff

NREL Principal Investigator:	Maureen Hand
NREL Field Test Engineer:	Richard Osgood
NREL Field Test Support:	Dave Jager
NREL IT Support:	Jim Mittl
SNL Project Lead:	Mark Rumsey
SNL Technical Project Lead:	Jose Zayas
SNL Field Test Support:	Perry Jones, Wesley Johnson
GE Energy Project Lead:	Troy "TC" Patton
GE Energy Field Test Support:	Mark McQuillen

Visual Tour of the Test Site

Tower Ladder to 2nd of 5 tower landings



SNL Master Data Acquisition System

Inside the nacelle